Resilient Multi-Terminal HVDC Networks with High-Voltage High-Frequency Electronics

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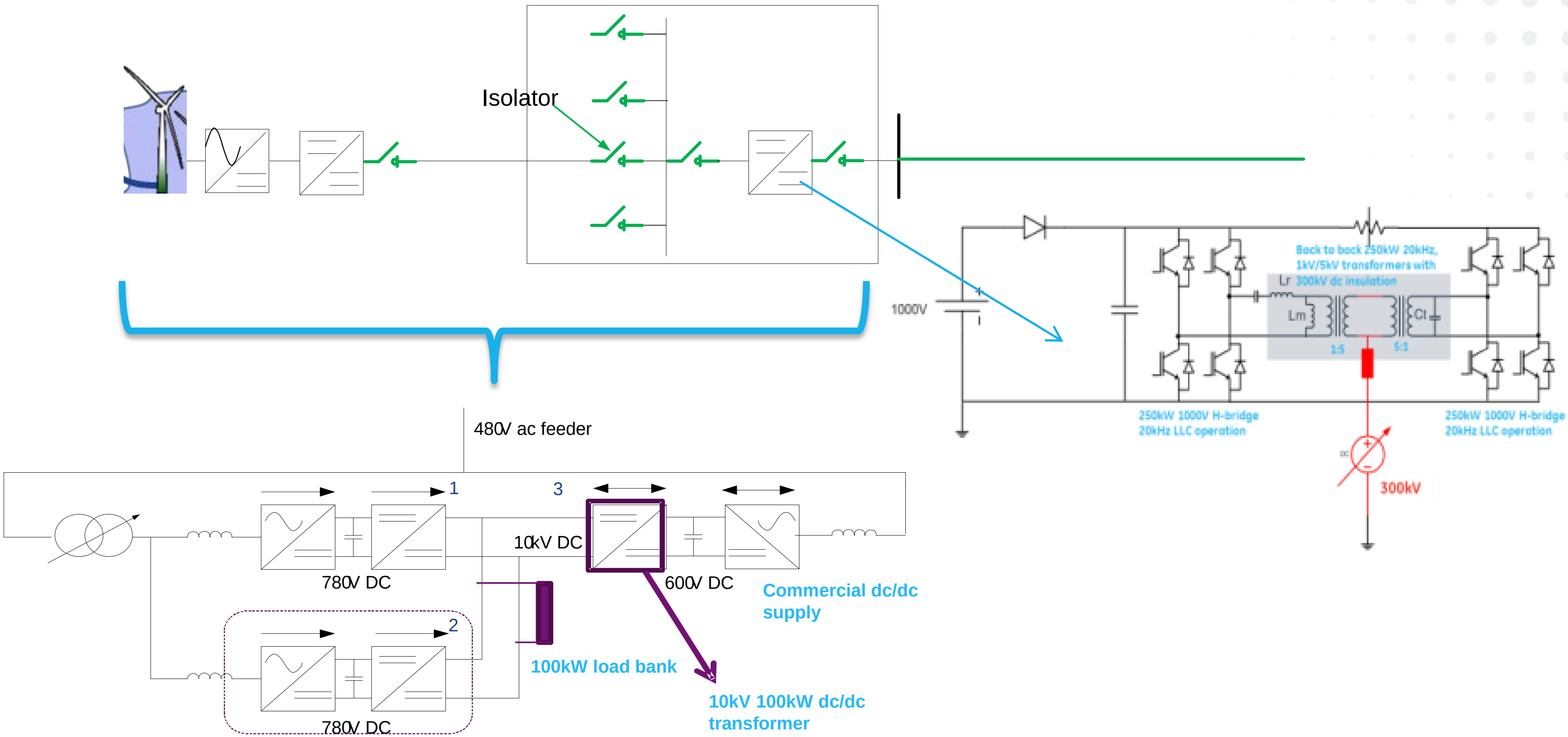
Award No. DE-AR0000224

GE Global Research

Project Objectives

- Overall goal: Develop components, architecture and controls for fault-resilient multi-terminal DC power system
  - Multi-terminal system, and DC/DC transformer
- Decrease cost and complexity and losses
  - Reduce number of components and conversions
- Published DC/DC transformers with AC stage up to 500Hz
  - GE project using 20kHz, to reduce physical size
- Performance metrics:
  - Losses, overall system cost
- Universities' focus on system-level for wind and solar applications

System Diagram



arpa·e CHANGING WHAT'S POSSIBLE
GE Global Research
Rensselaer
NC STATE UNIVERSITY

2014 Achievements

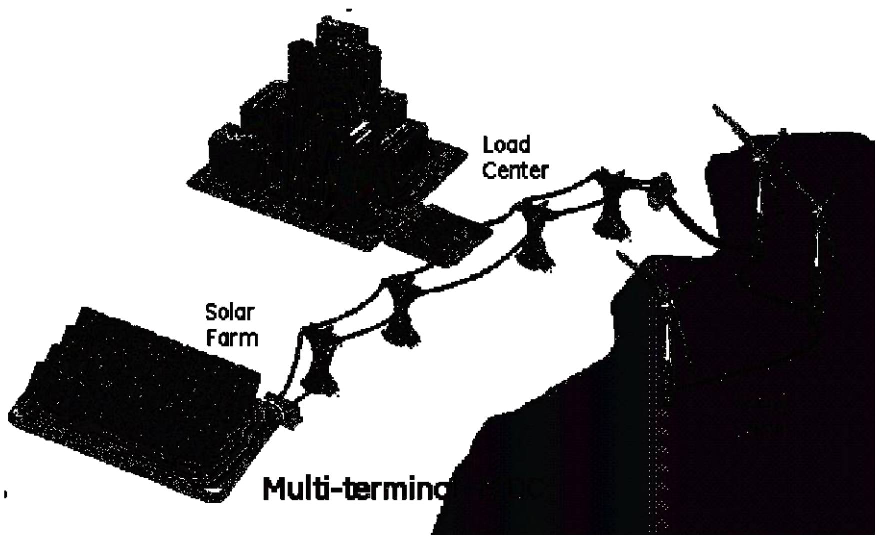
- 300kV DC offset voltage, with 2 x 250kVA on DC/DC transformer
  - Discrepancy between design and as-built transformer
  - Difficulties with 300kV cable connector into tank
- Demonstration of MTDC system and control performance –12 modules, 10kV/600V, 100kW
  - Complexity to control series-connected devices
  - Simulation and HIL implementations by Universities

Project Achievements

- Successful demonstration of system architecture and enabling technologies
  - Understanding working multi-terminal control system
  - Improved understanding of transformer design to consider 3-D modelling
- Remaining challenges:
  - Long-term impact of high-frequency stress on insulation
  - Packaging for scalability into system-level HVDC DC/DC transformer
  - Performance under actual fault conditions

Technology-to-Market

- Ultimate objective: Transition to a GE business
- Several potential markets
  - Subsea, Marine, Renewables (Solar, Wind), Utilities
- Difficulty in validating costs
  - CAPEX
  - OPEX
  - Installation
  - Maintenance
  - Disposal



Post ARPA-E Goals

- GE internal program to build on this work
- Remaining technical challenges:
  - Packaging for reliability and maintainability
  - Long-term high-frequency stress on insulation
  - Field demonstration

Conclusions

- Working practical demonstrations for multi-terminal network and DC/DC transformer
  - Enhanced understanding of transformer design and construction
  - Assisted development of 300kV connector supplier
  - Identified risks to be addressed in next phase of development

- Within GE, established core multi-disciplinary team

Nanoclay Reinforced Ethylene-Propylene-Rubber for Low-Cost HVDC Cabling

Dr Qin Chen

Electrical Engineer

January 14, 2015

Award No. DE-AR0000231

GE Global Research

ELECTRIC CABLE COMPOUNDS
Quality Compounding for the Wire and Cable Industry

Southwire®
WE DELIVER POWER... RESPONSIBLY

Project Objectives

- Overall goal: Develop new, low-cost insulation for high-voltage direct current (HVDC) electricity transmission cables.
  - New insulation by embedding nano-materials into specialty rubber
- Decrease system-level cost
  - Increase power density
  - Decrease manufacture time and cost

State of the art

Lapped cable with multilayer structure

http://en.wikipedia.org/wiki/File:HVDC_Submarine_Cable_Cross_Section_-_from_New_Zealand_Inter-island_scheme.jpg

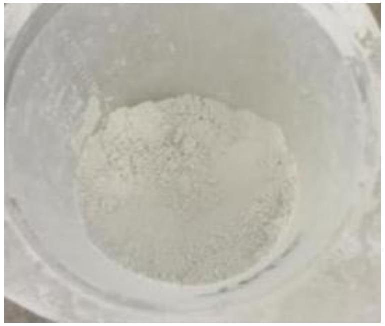
Extruded cable with uniform structure

http://upload.wikimedia.org/wikipedia/commons/8/82/Hochspannungskabel_110kV_400kV.JPG

DC Nanoclay-EPR: Experimental

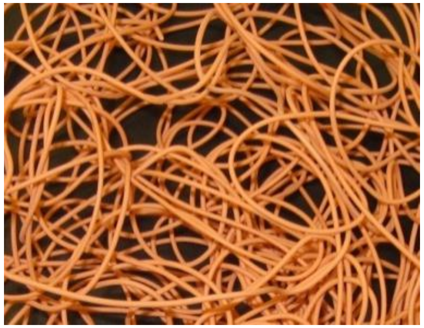
Polymer (EPR) resin

Nanoclay filler



Mix with additives

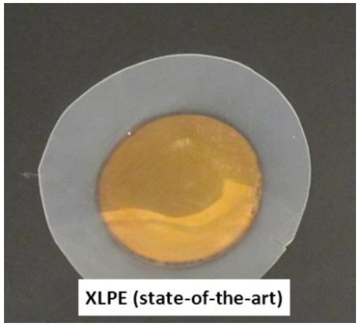
Compounded material

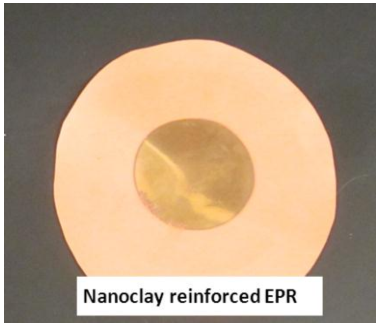


EPR: ethylene-propylene-rubber;
XLPE: crosslinked polyethylene

Melt press, crosslink

Sheet samples for electrical testing



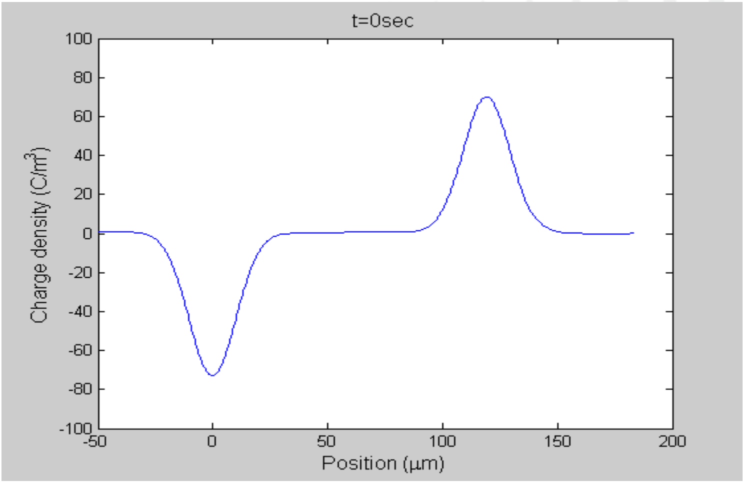


More than 30 compositions studied, with different filler types, loadings, surface treatments

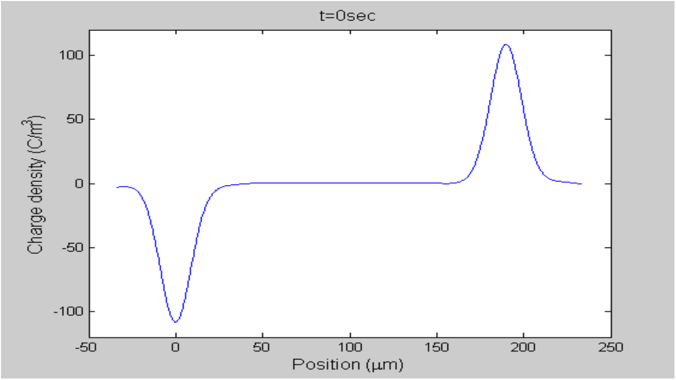
2014 Achievements

- 50kV DC cable prototype successfully extruded using AC EPR cable fabrication process
  - DC nanoclay-EPR insulation (345 mil), copper conductor (107 mm^2)
- Promising lab test results
- 160kV breakdown
  - QA test, space charge
- Endurance testing ongoing
  - 92.5kV, no breakdown

DC XLPE ***after degasing (80°C, 5 days)***



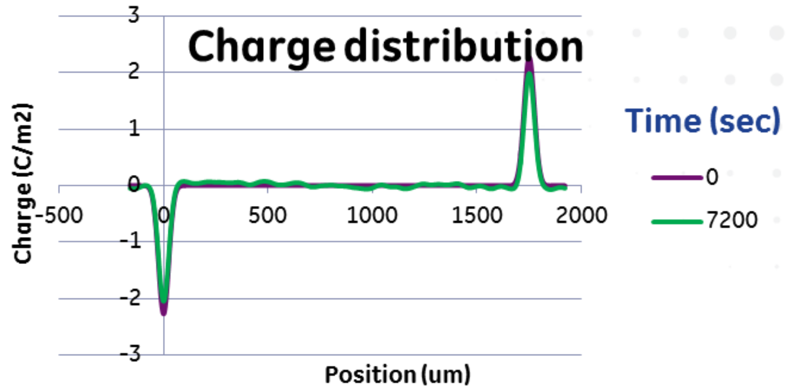
N-EPR, ***without degasing***

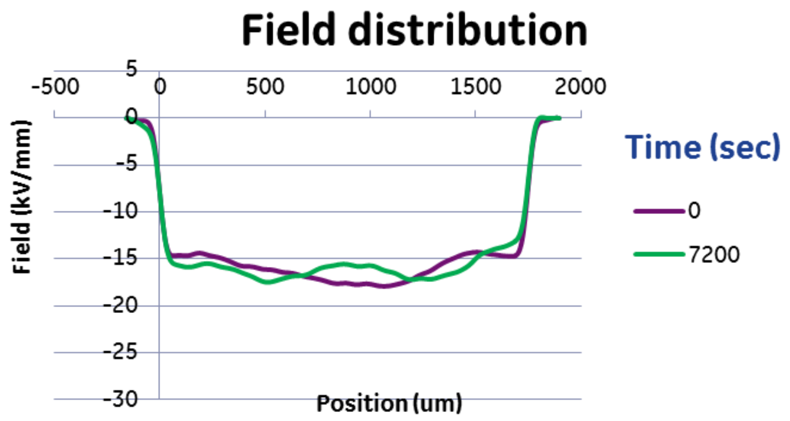


Remaining challenges

- Better understanding of the role of nanoclay morphology & electrical properties on DC conduction and space charge behavior

- Standard qualification test for the cable prototype





16.5 kV/mm field; 60°C with 2°C/mm gradient (anode cold)

Project Achievements

- Novel type of nanoclay reinforced Ethylene-Propylene-Rubber (EPR) has been developed, aiming at achieving layered structure in an extruded insulation
- Good HVDC performance and wide applicability
  - More than 30 compositions studied, with different filler types, loadings, surface treatments
  - Compromise between breakdown shape factor, thermal conductivity and relaxation time constant



Technology-to-Market

- Ultimate goal: Leverage new insulation material to reduce overall HVDC system costs

- Developed partnership with cable manufacturers
  - Ongoing discussions about potential JV / licensing opportunities with possible partners

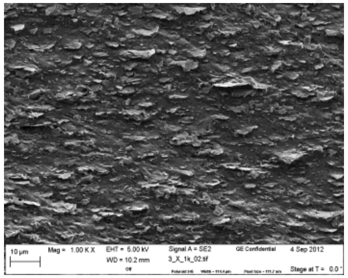
- Accessory development required

- Field trial required
  - Conservative customers

Conclusions

- Significant technical progress with prototype at meaningful voltage level (50kV DC)
- Established key relationship with cable manufacturer
- Initial indications of good commercial viability

Novel DC Nanoclay-EPR



- **Extruded cable with *<u>layered</u>* structure**

- ***AC*** **nanoclay-EPR is a mature technology**
- **Design for DC: morphology, electrical**